UNIVERSIDADE FEDERAL DO RIO DE JANEIRO
Centro de Ciências da Saúde
Instituto de Biologia
Departamento de Biologia Marinha

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Uma nova ameaça: Avaliando as principais interações entre peixes marinhos e detritos plásticos através de uma perspectiva cientométrica

Rio de Janeiro, RJ
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Marcelo Santos de Moura

A new threat: Assessing the main interactions between marine fish and plastic debris from a scientometric perspective

Monografia apresentada ao Departamento de Biologia Marinha para obtenção do Diploma de Biólogo – Habilitação Bacharelado em Biologia Marinha – Instituto de Biologia – UFRJ

Orientador**:** Prof. Dr. Marcelo Vianna

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"O método científico é comprovado e verdadeiro. Não é perfeito, é apenas o melhor que temos. Abandoná-lo, junto com seus protocolos céticos, é o caminho para uma idade das trevas."

Carl Sagan

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RESUMO

Os impactos gerados pela poluição dos detritos plásticos são um dos grandes desafios que a humanidade terá que enfrentar neste próximo século, fato este que tem recebido cada vez maior atenção da mídia. Assim sendo, quantificar o estado da arte dos organismos afetados por detritos plásticos, seja qual for seu tamanho, é um trabalho de extrema importância para o entendimento de ameaças as espécies marinhas que interagem com estes. O presente trabalho teve por objetivo revisar e quantificar dados existentes de quais espécies de peixes marinhos, são reportados interagindo com resíduos plásticos através de uma análise cientométrica, nas bases Web of Science, Scopus e Scielo; utilizando uma combinação de palavras-chaves e operadores booleanos. Apesar de nenhum resultado encontrado para Agnatha, Holocephali e Sarcopterigii, a revisão registrou 116 documentos relatando fortemente interações de ingestão e emaranhamento, em 310 espécies de peixes teleósteos e 33 espécies de Elasmobrânquios. Os resultados indicam o crescimento da produção do conhecimento a partir de 2012, relatando uma diversidade de cores, formatos e materiais distribuídos ao longo do globo, apesar da maior concentração de esforços de pesquisas no Atlântico Nordeste e nos mares Mediterrâneo e Negro. O trabalho fornece diversas análises, perspectivas e sugestões para futuros trabalhos, levantando informações valiosas para tomadas de decisões visando a preservação das espécies marinhas, buscando entender melhor a problemática destes poluentes emergentes que representam mais uma ameaça a fauna dos oceanos do mundo.

Palavras-chave: Ecologia de Peixes, Lixo Marinho, Microplástico, Poluição Marinha, Revisão Cientométrica.

ABSTRACT

Impacts generated by plastic pollution constitute one of the most significant challenges that humanity must face in the next century, receiving increasing attention from the society at large. Thus, quantifying the state of knowledge concerning organisms affected by plastic debris is extremely important to understand threats to marine species. In this context, this study aimed to review and quantify published data on which marine fish species have been reported as interacting with plastic waste through a scientometric analysis carried out on the Web of Science, Scopus and Scielo databases, using a combination of keywords and Boolean operators. Despite no results for Agnatha, Holocephali and Sarcopterigii, this survey registered 116 documents reporting high intake and low entanglement interactions for 310 teleost species and 33 Elasmobranchs. The results indicate increased knowledge production after 2012, reporting a diversity of debris colors, shapes and materials distributed throughout the globe, but with greater research efforts performed in the Northeast Atlantic and the Mediterranean and Black Seas. This study provides analyses, perspectives and suggestions for future assessments, gathering information and seeking to better understand the issue concerning these debris, which represent another threat to the fauna of the world's oceans.

Keywords: Microplastic, Marine Litter, Scientometric, Marine Pollution, Fish Ecology

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1. INTRODUÇÃO

Com o passar dos tempos cada vez mais há uma crescente preocupação com questões que se relacionam intrinsicamente com os diversos fenômenos, desastres, estabilidade e manutenção do meio ambiente. Não obstante, a preocupação com a poluição ambiental vem tomando a mesma tendência crescente, principalmente no que tange a poluição por resíduos sólidos, onde reside o aumento com a preocupação com a poluição com resíduos plásticos nos oceanos *per se*. Os resíduos plásticos constituem a maior parte do lixo de resíduos sólidos no oceano (Galgani *et al*., 2015). O impacto do plástico se estende em proporções globais, visto que projeções mundiais estimam que em 2050 haverá mais plástico que peixes em biomassa no oceano (World Economic Forum, 2016), e a deposição de plástico formando registros estratigráficos podem acabar marcando geologicamente a era do Antropoceno (Zalasiewicz *et al.*, 2016).

Os polímeros plásticos, são particularmente diferentes e agrupam diversos tipos de macromoléculas que possuem baixo custo de produção e alta durabilidade. No entanto essas características e propriedades o tornam objetos perigosos para os diferentes habitats e ecossistemas, quando descartados e despejados de forma não apropriada devido à falta de manejo adequado, como vem sendo um fenômeno comumente, amplamente e frequentemente realizado em diversos países do mundo (Rochman *et al.*, 2013; Jambeck *et al.*, 2015). Interações com detritos e resíduos plásticos, de diversos tamanhos, cores, formatos e composições podem ter uma ampla série de efeitos deletérios nos organismos que interagem de forma ampla a nível populacional, causando diferentes consequências ecológicas ou individuais (Kühn *et al.*, 2015; Markic *et al.*, 2020).

Diferentes espécies marinhas acabam interagindo com os detritos plásticos no mar, como tartarugas, aves e mamíferos marinhos (Laist, 1997; Kühn *et al.*, 2015). Entretanto o mesmo esforço para observar as espécies de peixes não é aparentemente empregado. Quando o assunto são os peixes como um todo, os relatos de interação com teleósteos parecem bem mais comuns, em comparação aos outros membros desse grupo, que passam a ser comumente negligenciados, quando o grupo de estudo refere-se a peixes *lato sensu*. Observando plásticos que se acumulam em praias, é possível identificar marcas de mordidas que denotam interações com elasmobrânquios, um grupo frequentemente negligenciado nas amostragens (Carson, 2013).

Dados científicos após a revisão por pares costumam ser publicados em revistas especializadas que tem sua credibilidade atestada no aferimento e avaliação se o método científico foi propriamente utilizado. Revistas científicas podem ser indexadas em bases de dados destinadas a divulgação das informações, assim ampliando o escopo de impacto daqueles trabalhos. As bases de dados científicos podem indexar trabalhos de revistas que afiram qualidade aos elementos publicados. Algumas bases de dados possuem seu acervo monitorado por uma curadoria e possuem um motor de busca que passa por frequente calibração, permitindo o uso de caracteres que favorecem o escopo de busca, chamados de operadores booleanos.

Uma análise cientométrica tem por objetivo principal compreender quais trabalhos estão sendo indexados, em certas bases de dados científicos. Assim, inserindo uma combinação de palavras-chave e operadores booleanos, cria-se um código para a busca de estudos específicos relacionados a um campo de pesquisa desejado. Assim, outrora revisar esses dados publicados, torna-se uma interessante e importante metodologia de revisão de dados, aos quais permitem levantar uma conveniente perspectiva de revisão do assunto analisado e tendo sido bem sucedida em diversos artigos (*e.g.* Santos e Vianna, 2018; Souza e Vianna, 2020).

Portanto o presente trabalho teve como objetivo revisar o conteúdo publicado nas principais bases de dados científicos do mundo sob uma perspectiva cientométrica, inserindo palavras-chave e operadores booleanos específicos. Assim, revisando os artigos publicados para todos os grupos pertencentes ao que se refere ao grande grupo “peixes” *latu sensu*, buscando compreender sua dimensão de publicação e reportar para as espécies dos grupos *stricto sensu* que o compõem, isto é: Actinopterygii, Sarcopterygii, Elasmobranchii, Holocephali e Agnatha.

2. INFORMAÇÕES DO ARTIGO SUBMETIDO

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We are pleased to inform you that your submission A new threat: Assessing the main interactions between marine fish and plastic debris from a scientometric perspective has been accepted for publication in Reviews in Fish Biology and Fisheries.

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A new threat: Assessing the main interactions between marine fish and plastic debris from a scientometric perspective

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Abstract:	Impacts generated by plastic pollution constitute one of the most significant challenges that humanity must face in the next century, receiving increasing attention from the society at large. Thus, quantifying the state of knowledge concerning organisms affected by plastic debris is extremely important to understand threats to marine species. In this context, this study aimed to review and quantify published data on which marine fish species have been reported as interacting with plastic waste through a scientometric analysis carried out on the Web of Science, Scopus and Scielo databases, using a combination of keywords and Boolean operators. Despite no results for Agnatha, Holocephali and Sarcopterygii, this survey registered 116 documents reporting high intake and low entanglement interactions for 310 teleost species and 33 Elasmobranchs. The results indicate increased knowledge production after 2012, reporting a diversity of debris colors, shapes and materials distributed throughout the globe, but with greater research efforts performed in the Northeast Atlantic and the Mediterranean and Black Seas. This study provides analyses, perspectives and suggestions for future assessments, gathering information and seeking to better understand the issue concerning these debris, which represent another threat to the fauna of the world's oceans.	

3. ARTIGO

A new threat: Assessing the main interactions between marine fish and plastic debris from a scientometric perspective

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3.1 Abstract

Impacts generated by plastic pollution constitute one of the most significant challenges that humanity must face in the next century, receiving increasing attention from the society at large. Thus, quantifying the state of knowledge concerning organisms affected by plastic debris is extremely important to understand threats to marine species. In this context, this study aimed to review and quantify published data on which marine fish species have been reported as interacting with plastic waste through a scientometric analysis carried out on the Web of Science, Scopus and Scielo databases, using a combination of keywords and Boolean operators. Despite no results for Agnatha, Holocephali and Sarcopterygii, this survey registered 116 documents reporting high intake and low entanglement interactions for 310 teleost species and 33 Elasmobranchs. The results indicate increased knowledge production after 2012, reporting a diversity of debris colors, shapes and materials distributed throughout the globe, but with greater research efforts performed in the Northeast Atlantic and the Mediterranean and Black Seas. This study provides analyses, perspectives and suggestions for future assessments, gathering information and seeking to better understand the issue concerning these debris, which represent another threat to the fauna of the world's oceans.

Keywords: Microplastic, Macroplastic, Scientometric Review, Osteichthyes, Sharks, Rays

3.2 Introduction

Plastic waste has increasingly received media attention and corresponds to most of the solid waste present in the marine environment (Galgani et al. 2015). Worldwide plastic production and disposal are closely related to population growth and demands. Future projections by the World Economic Forum (2016) have indicated an exponential growth of plastic production, accounting for 20% of the world's oil consumption and increased plastic leakage into the ocean, resulting in more plastic in the oceans than fish biomass by the year 2050.

Plastic polymers present different compositions appreciated for their durability and low production cost. However, these characteristics also make them a problematic environmental waste when improperly disposed of. Plastics of various sizes are found across the globe, in several environments, such as beaches, close to continents, in densely populated areas, and even in remote areas such as oceanic islands, deep seas, poles and oceanic gyres (Barnes et al. 2010, 2018; Van Sebille et al. 2012; Eriksen et al. 2013; Ivar do Sul et al. 2013; Ivar Do Sul et al. 2014; Jambeck et al. 2015; Lusher et al. 2015; Woodall et al. 2015; Munari et al. 2017; Bergmann et al. 2017; Cincinelli et al. 2017; Monteiro et al. 2018; Hamid et al. 2018; Erni-Cassola et al. 2019; Filho et al. 2019; Kane and Clare 2019). Accumulations are formed in areas where currents converge and form, such as an area located in the Pacific gyre, resulting in areas of accumulation, potentially associated to greater marine biota interactions due to higher environmental frequencies (Van Sebille et al. 2012; Eriksen et al. 2013). These plastic residues can be classified according to size and shape, usually categorized into different classification directives (Hanke et al. 2013; GESAMP 2015; Lusher et al. 2017a; GESAMP 2019; Hartmann et al. 2019). As this is a new field of research, still under development, no consensus on the correct definition of macro-, meso-, micro- or nano- plastic size limits are available, although several classifications suggesting different limits have been noted, which may cause problems due to lack of standardization (Lusher et al. 2017a, b; Collard et al. 2019; Hartmann et al. 2019).

Plastic waste is considered hazardous, due to several risks concerning ecological implications and how pollution by this type of solid waste can affect marine organisms (Rochman et al. 2013a). Marine biota interactions with macro- and micro- plastic wastes are worrisome phenomena and may contribute to several consequences such as mortality and negative metabolic and physiological effects (Kühn et al. 2015; Lusher et al. 2017a; Zhang et al. 2019). The smaller the plastic size, the higher the risk of internal translocation to tissues, leading to risks to internal organs, i.e. the liver (Wright et al. 2013; Galloway 2015; Collard et al. 2017; Lusher et al. 2017a; Abbasi et al. 2018). The most commonly reported plastic interactions are ingestion and entanglement, each resulting in its own deleterious effects (Laist 1997; Carson 2013; Kühn et al. 2015). These effects may result in organism-level consequences, leading to lethal and sublethal effects in individuals, which may, in turn, generate population-level consequences, i.e. decreased recruitment and survival rates, if affecting several specimens belonging to the same population (Markic et al. 2020). Macroplastic waste interactions in fishes are usually associated to entanglement but may also be associated to ingestion (Carson 2013; Murphy et al. 2017; Menezes et al. 2019). Prolonged entanglements is a very serious issue, due to the fact that it may cause tissue damage, body structure deformation, difficulties in breathing and feeding, mobility problems, and the death of different marine vertebrate groups including teleosts and elasmobranchs (Laist 1997; Wegner and Cartamil 2012; Kühn et al. 2015; Nelms et al. 2016; Stelfox et al. 2016; Colmenero et al. 2017; Parton et al. 2019). Ingestion of macro-, micro- and nano- plastic debris is associated with intestinal inflammation, hepatic and oxidative stress, endocrine disruption, physical injury and inflammatory responses (Rochman et al. 2013c, 2014; Wright et al. 2013; Qiao et al. 2019; Stock et al. 2019), while also being a source of persistent organic pollutants and metal accumulations, with widely accepted toxic effects (Gregory 1996; Derraik 2002; Rios et al. 2007; Hirai et al. 2011; Rochman et al. 2013b, c, d, 2014; Brennecke et al. 2016; Lusher et al. 2017a; Filella and Turner 2018; Wang et al. 2019; GESAMP 2019; Lee et al. 2019). In addition, trophic microplastic and nanoplastic particle transfer has also been observed, resulting in both ecological concerns and a number of risks in relation to food security on humans (Galloway 2015; Lusher et al. 2017a; Barboza et al. 2018; Carbery et al. 2018; Chagnon et al. 2018; Nelms et al. 2018; Wang et al. 2019).

Unlike mammals, turtles and seabirds, the potential impacts of solid waste on fish, however, are not frequently reported (Laist 1997; Kühn et al. 2015). Even so, Ripple et al. (2019) estimate that this pollution is the most important threat to Chondrichtyes and Actinopterygii specimens after fisheries activities. Some reviews on interactions between marine fish and plastic debris have been carried out using different methodologies (Laist 1997; Deudero and Alomar 2015; Kühn et al. 2015; Stelfox et al. 2016; Colmenero et al. 2017; Kroon et al. 2018; Parton et al. 2019; Markic et al. 2020). However, the authors of these assessments treated fish without verifying exactly what specific categories make up this large group. The exception are the studies carried out by Stelfox et al. (2016), Colmenero et al. (2017) and Parton et al. (2019), who specifically reported on solid waste interactions in Elasmobranchs. However, despite the immense contribution that these studies have provided, it is still necessary to understand other issues, such as which fish species are most affected and by what type of waste. Considering fish as a homogeneous group may not be the most appropriate way to understand which marine organisms are most affected, as a risk of underestimating the different categories that comprise this large group, such as cartilaginous fish, is noted. Scientometric reviews aim to understand the state of knowledge and search the main literature dealing with a given subject, gathering documents that go through peer and indexed reviews. This methodological approach has been used by several authors, with excellent results (i.e. Santos and Vianna 2018; Souza and Vianna 2020). However, the choice of search words must be meticulous in order to select the maximum number of articles dealing with the subject without contaminating the search with unwanted articles. In this context, the aim of this study was to assess available knowledge reported in the scientific literature concerning marine fish interactions with plastic waste by analyzing historical records, spatial distribution, related taxa, type of interaction and the characteristics of the reported plastic material.

3.3 Material and methods

A scientometric analysis was carried out at the Web of Science, Scopus and Scielo scientific databases, between June 2018 and January 2019. The search and choice of keywords and Boolean operators followed a research methodology where three fields were used to define the search steps, all connected by the AND option in the connection boxes from one to the other. The first search field was defined to insert the words related to plastic waste, reported as the most common in Lusher et al. (2017b): "*plastic$ OR debris OR litter OR rubbish OR garbage OR waste OR trash". The second field comprised keywords related to fish, with the following terms used for Teleostei: "*fish OR *fishes" and "osteicht* OR teleost* OR actinopter* OR *teleostei OR ray-finned"; for Elasmobranchs: "shark$ OR stingray$ OR skate$ OR elasmobran* OR chondricht* OR ray$"; for Holocephali: "chimaera$ OR holocepha* OR chondricht* OR chimaerifor*"; for Agnatha: "hagfish* OR jawless OR "jawless fish*" OR mixyni* OR cyclostomata OR agnat* OR lamprey$ OR hyperoartia OR petromyzonti*"; and for Sarcopterygii: "osteicht* OR sarcopter* OR lungfish OR dipnoi OR ceratodonti* OR neoceratod* OR lepidosiren* OR protopter* OR actinistia OR coelacanth*OR latimer* OR lobe-finned". The third field consisted of keywords chosen based on interactions reported at Litterbase (https://litterbase.awi.de/interaction_graph) plus words aiming to obtain food ecology studies: "ingest* OR entang* OR coloni* OR cover* OR stomach* OR gastrointestinal* OR digestive* OR tract$”. A preliminary search was carried out in order to check the word marking and observe the efficiency of the applied keywords and the inserted Boolean operators. Thus, the other search fields were filled out using the NOT connection fields to exclude undesirable results and decrease the number of undesirable results, as follows: “neoplastic$”, “anaplastic$”, “”cell debris””, “”litter size$””, “”wood* debris””, “”leaf debris””; “”leaf litter””.

After defining the search fields, a preliminary research was carried out to select which articles, in fact, referred to interactions between fish and plastic waste, discarding undesirable results by analyzing the title, abstract and keywords of the obtained articles. Subsequently, another analysis was conducted on all selected articles, with the aim of recording species, interactions, regions, and risk of extinction, as well as other information related to the reported residues, such as type, shape, composition, size, color, in addition to sample number and frequency of occurrence (i.e. frequency of sampled individuals containing plastic). Only available information was considered, leaving missing information blank. Data on risk of extinction and region of occurrence were obtained from the fishbase.org website. As certain articles did not accurately indicate the study area, location data was processed using large fishing grounds, as reported by the FAO (http://www.fao.org/fishery/area/search/en). Articles were only excluded when not indicating the studied species or study area, when not published in an indexed scientific journal, when no digital publication was available in English or when the nature of the ecosystem, whether marine, fluvial or aquaculture, was not clearly identified, since the latter two were not considered in the present study. In spite of disparities concerning article quality, for example regarding different methodologies, no article was excluded based on its applied methodology or quality. Report credibility may occasionally be questioned, as article quality vary due to the application of different methodologies and the absence of certain protocols, such as a viable sample size and polymer identification (Hermsen et al. 2018). In addition, semi-synthetic polymers (e.g. rayon, cellophane, regenerated cellulose) were also considered herein, as these particles may often be reported only as plastics, with no distinction between synthetic and semi-synthetic particles (e.g. Neves et al. 2015; Halstead et al. 2018) as proposed by Kroon et al. (2018). Other anthropogenic particles, such as cotton, were not considered in this survey, unless their occurrence was associated with plastic waste.

3.4 Results

A total of 116 articles were found reporting on plastic waste and fish interactions between 1972 and 2018, at the Web of Science and Scopus databases, with no results from

Scielo. No records were obtained for Holocephali, Sarcopterygii and Agnatha. Most publications were reported from 2012. Prior to this date, only sporadic records were noted, indicating an increasing trend in scientific production on the topic (Fig. 1). A total of 343 species were cited, among which 310 were teleosts, distributed in 23 orders and 92 studies, and 33 were elasmobranchs, comprising 6 rays and 27 sharks, distributed in 8 orders and 24 studies.

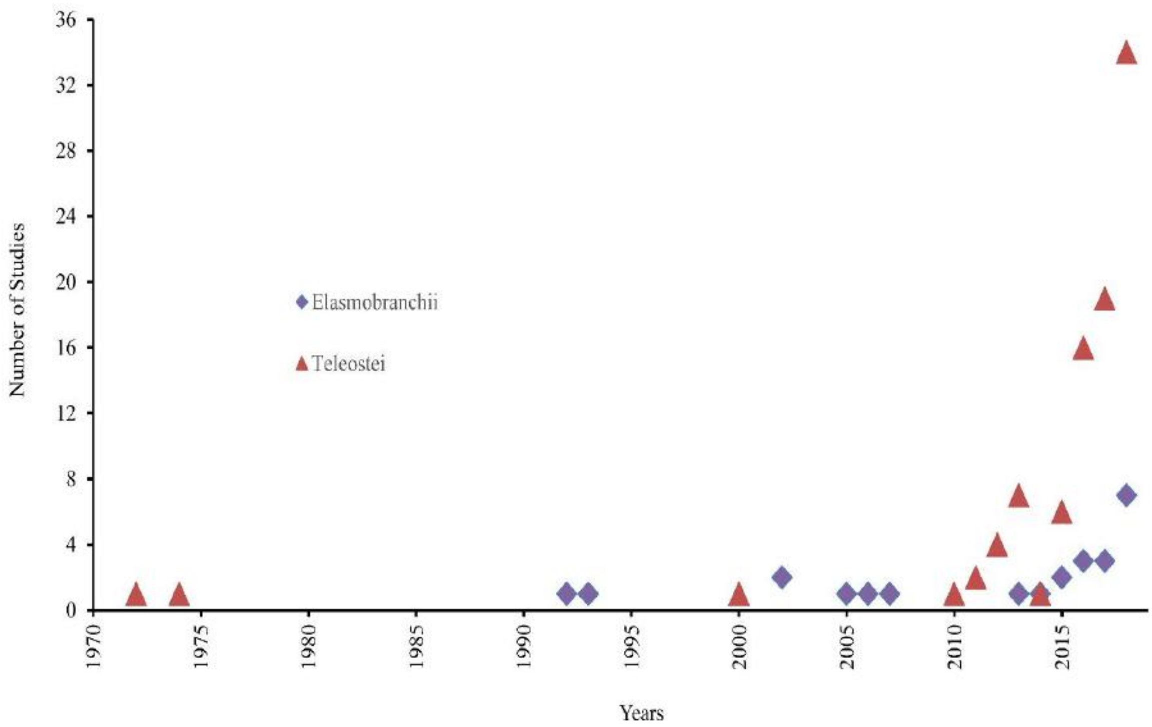

Fig 1- Number of publications, per year, on the interaction of marine fish with plastic waste, for Elasmobranchs and Teleosts.

Concerning spatial distribution, different parts of the world were reported in the obtained studies. Most were carried out in the Northeast Atlantic (Area 27, 24.5% to teleosts, 19% to elasmobranchs) and the Mediterranean and Black Seas (Area 37, 17% to teleosts, 22% to elasmobranchs), for both teleosts and elasmobranchs. The highest number of recorded species interacting with plastic was also observed for the Northeast Atlantic (Area 27, 20%) and the Mediterranean and Black Seas (Area 37, 16%), followed by the Southwest Atlantic (Area 41, 15%) (Fig. 2 and 3).

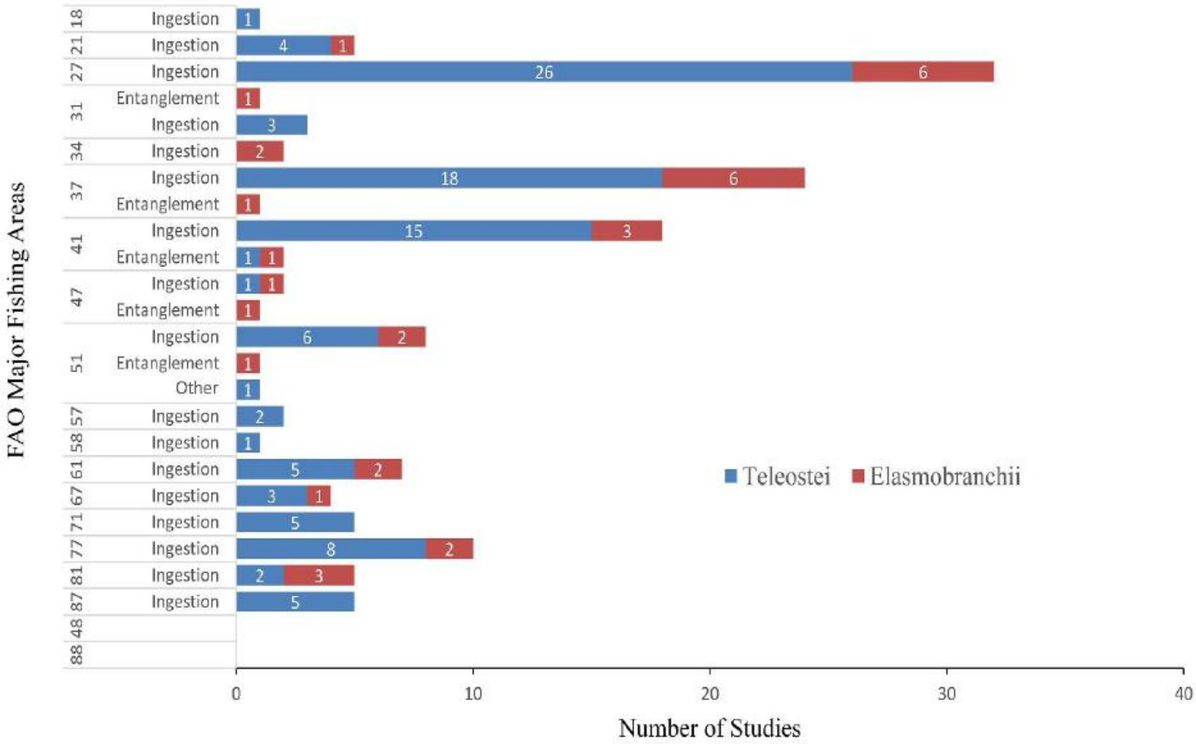

Fig 2- Number of studies carried out in FAO fishing areas (http://www.fao.org/fishery/area/search/en), on the interaction marine fish interactions with plastic debris and their respective reported interactions, by taxon.

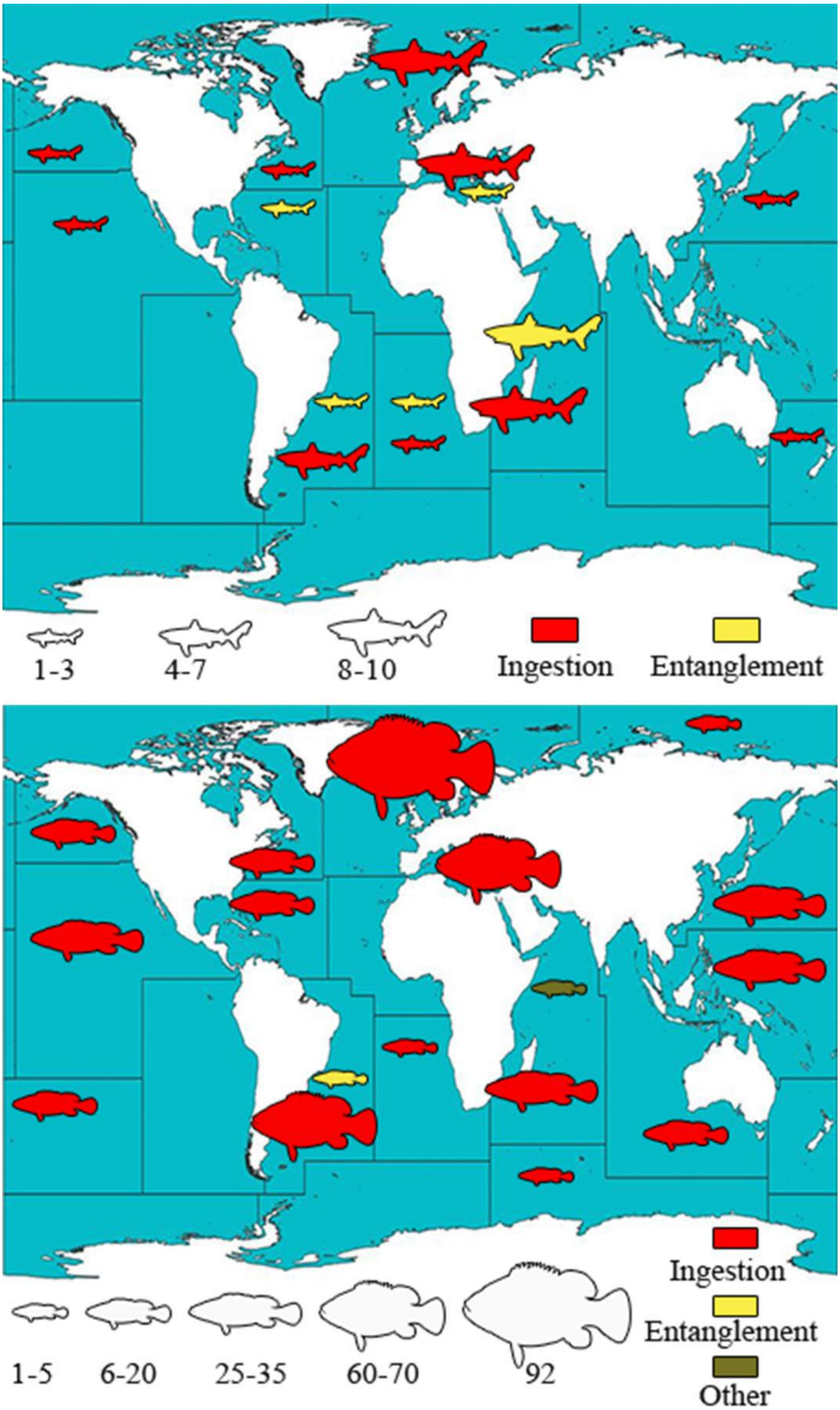

Fig 3- Distribution of marine fish species and their interactions with plastic debris in FAO fishing areas (http://www.marineregions.org/downloads.php#fao), where: A: Elasmobranchs and **B:** Teleosts.

3.4.1 *Teleosts*

Over half (65%) of the cited species are classified as Least Concern (LC) and 28% have not yet been assessed (NA) regarding their risk of extinction, with other categories ranging from less than 1% to 3% (Fig. 4). Almost all species (98%) were reported as ingesting plastic materials of varying in size, with microplastics being the most reported (57.5%) (Fig. 4). A total of 47 colors were mentioned, the most common being black (13.9%), blue (15.8%), red (11.1%), green (9.2%), and white (9.2%). These colors appeared in over 8% of all citations, while the other 42 colors appeared at less than 5% each (from 5% to 0.3%). A considerable number of assessments (33%) did not report any plastic color, while 67% did.

Plastic shape diversity was high, as well as polymer composition. Of the 45 reported shapes, the most common were fragments (22%) and fibers (20.2%). Films made up the third most common shape (7.8%), although mentioned only 17 times, while the other 42 shapes were reported less than 7% each (from 6% to 0.5%). A considerable number of studies (41%) did not report polymeric composition, as many authors did not evaluate this characteristic. Ignoring this analysis may lead to lack of comparability of plastic debris patterns in different species and oceanic regions. The most recorded compositions were polyethylene (12.7%), polypropylene (11.5%), polyamide/nylon (11.5%), polyester/polyethylene terephthalate (10.4%), polystyrene (5.4%), acrylic (3.8%) and polyvinyl chloride (3.1). Other polymers comprised less than 3% of the citations each (from 2.3% to 0.4%). Composition was mentioned in 59% of the studies. The vast majority of polymers were identified by the Fourier Transform Infra-Red (FT-IR) technique.

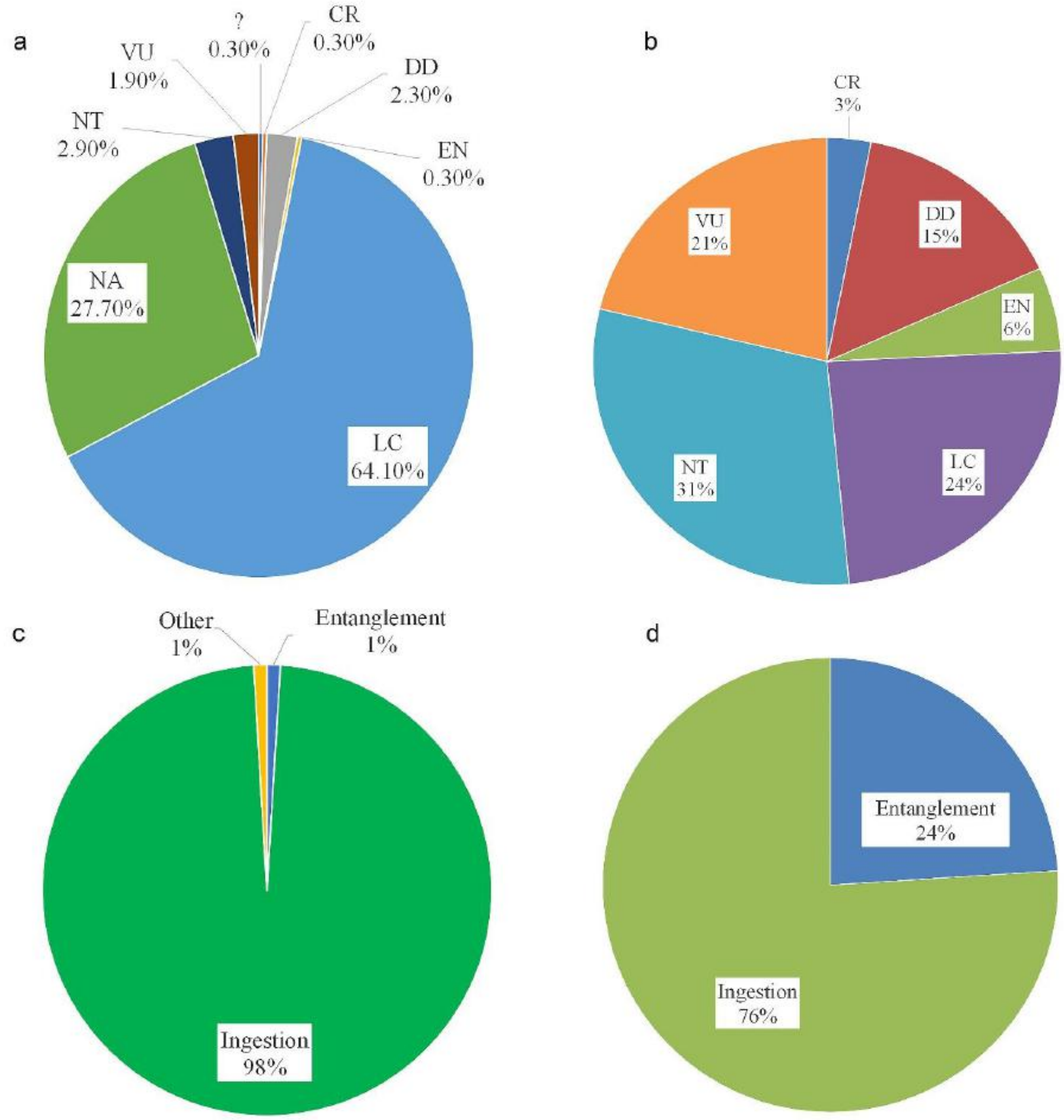

Fig 4- A: Proportion of reported teleost species and their respective degrees of threat, displayed as total number and percentages, respectively; B: Proportion of reported elasmobranch species and their respective degrees of threat, displayed as total number and percentages, respectively. C: Proportion of teleost species and their respective reported interactions; D: Proportion of elasmobranch species and their respective reported interactions

3.4.2 *Elasmobranchs*

Most reported shark and ray species are classified as Least Concern (LC, 24%) or Near Threatened (NT, 31%), while some present a certain degree of threat (VU, EN, CR, 30%) or are Data Deficient (15%), as presented in Figure 4. A total of 76% of the reports were related to plastic ingestion, while 24% reported entanglement (Fig. 4). Most interaction material was reported as microplastics (41.9%). Most studies did not mention color (63%), but the most reported colors among studies that did so (37%) were blue (15.2%), red and black (both 12.1%).

Regarding shape, the most cited plastic debris shape were fragments (14.8%), lines (8.2%), fibers (8.2%), films (6.6%), bags (6.6%) and bands (6.6%). Concerning chemical composition, most studies did not report polymers (60%), but the most reported among studies that did so (40%) were Polyethylene and Polypropylene each mentioned in five different studies (10.6% each).

3.5 Discussion

The scientometric analysis indicated a high number of articles, even though the search was restricted to only three scientific databases. The advantage of these databases is due to the fact that their activities are monitored by a curator, who checks which magazines will be indexed, also calibrating the search engine while maintaining proper functioning. The search engine of these bases allows for the use of Boolean operators, thus expanding the possibilities of search term insertions or restrictions, maintaining a more comprehensive and assertive analysis. However, search engine limitations are still observed, which results in scientometric methodology restrictions when articles do not have the searched terms present in their title, abstract or keywords, where the search engine performs its recruitment. These documents are then not found and are excluded from searches. This was noted in the study carried out by Silva and Vianna (2018), who assessed the feeding habits of *Gymnura altavela* rays and notified straws and plastic films, but was not recruited because the aforementioned searched terms were not present in the study title, abstract or keywords. Using different databases, even with the possibility of using the exact same words and Boolean operators, may not reproduce the same result, due to differences between search engines and indexed collections. For example, Parton et al. (2019), using the Google Scholar database, found a record for Chimaera entanglement, whereas we did not. Therefore, we believe that the results reported herein are underestimated, which becomes a problem as the addressed subject is poorly understood and requires wide dissemination in order to sensitize the academy and society in general, so that they cover international recommendations and public policy implementations.

Sarcopterygii, Holocephali and Agnatha, displaying rarer marine biodiversity rates, did not appear in this assessment. Marine Sarcopterygii are endemic to certain locations in the Western Indian Ocean, off the African coast, and in Southeast Asia areas, all known for their water pollution and inefficient plastic waste handling (Todd et al. 2010; Jambeck et al. 2015; Hamid et al. 2018; Karthik et al. 2018). Holocephali and Agnatha are often found at great depths and unfrequently sampled locations, and the idea that these organisms are free of impact is false, since records of biota interactions with plastics in deep seas are available (Woodall et al. 2015; Chiba et al. 2018). These animals are unfrequently captured, and satisfactory sample sizes are not usually obtained. Alomar and Deudero (2017) analyzed two *Chimaera monstrosa* specimens and did not find any ingested plastic debris. Markic et al. (2020) report that a sample size of 10 individuals is the minimum satisfactory number for statistical confidence. Thus, more efforts are required to further analyze a higher number of representatives of these taxa, whose threats are often not well understood, as in the case of Mixiniformes, or those who are at risk of extinction, such as Latimeriidae. Therefore, understanding the problem is essential to verify if these groups have also been exposed to plastic pollution.

Plastic waste pollution interest has recently increased significantly. A clear growth trend in this interest is noted beginning in 2010, which can be explained by increased society concerns and awareness regarding this type of problem, as well as by the development and establishment of methodological protocols for ingestion verification, especially regarding microplastics. The global study distribution indicates that this knowledge is centralized, since most articles are concentrated in Europe, the Northeast Atlantic, and the Mediterranean and Black Seas. This may be a consequence of the creation of the Marine Strategy Framework Directive (MSFD) which aims to promote adequate environmental status and natural resources protection (available at: https://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm). Consequently, this centralization may occur due to the non-existence of a program like the MSFD in other developed countries, as well as inequality regarding science resources availability as a determining factor for less reports in poorer and developing countries. The Southwest Atlantic region is surprising as the third most studied region, as it is surrounded by developing countries. This region, despite not having a program like the MSFD, had resources destined for research through public development policies, which allow for the assessment of plastic interactions, especially on the Northeastern Brazilian coast, which presents most of the reports for teleosts.

Even with fewer studies in the Southwest Atlantic compared to the Mediterranean Sea, the South American Atlantic coast presents a reported teleost species relationship close to that of the Mediterranean and Black Seas, but still far from records for the Northeast Atlantic. Regarding biodiversity, the South American Atlantic coast is widely known to be richer compared to European seas. However, larger sampling efforts lead to a higher number of reports in these regions, including for the same species (i.e. *Sardina pilchardus*, *Mullus* *barbatus*, *Galeus melastomus*, *Scyliorhinus canicula*), whereas few species reported more than once were noted for South America (i.e. *Cynoscion acoupa, Atherinella brasiliensis, Rhizoprionodon lalandii*). Therefore, the number of fish species interacting with plastic waste, by region, does not correspond to greater local biodiversity, but to greater research efforts.

A considerable amount of teleost species recorded in this scientometric survey is classified as Least Concern (LC). Nevertheless, it is important to note that 28% of the other reported species have not even been evaluated by the IUCN. These species may be threatened by known problems, such as overfishing and habitat loss, but also by plastic pollution. Although 310 species were recorded, this is a small number in view of the known species richness. In this regard, increased efforts in assessing marine debris interactions with fish are required in order to quantify the threat of plastic pollution, aiming at species conservation, but also taking into account human health risks due to fish consumption, as many fish species display significant commercial importance.

Fewer elasmobranchs were observed. This difference appears both regarding sample number, the lowest among the analyzed studies, and number of registered species, also lower. This is probably due to the low catch rates for ray and sharks, in addition to lower diversity compared to teleosts. Elasmobranchs are top predators and usually considered key species in the ecosystems they inhabit, exercising the trophic cascade and maintaining ecosystem health. Nonetheless, this group is known for its susceptibility to overfishing, and understanding this new threat is essential in order to conserve these species (Heithaus et al. 2008; Bornatowski et al. 2014; Croll et al. 2016; Dulvy et al. 2017; Hammerschlag et al. 2018). Eight elasmobranch species reported herein (24%) are at little risk of extinction, while 45% display some risk or are data deficient. A much higher ratio compared to the analyzed teleosts was noted, and the greater number of threatened elasmobranch reports indicates significant concerns regarding their preservation, as plastic interactions are a new conservation threat to be considered.

Ingestion was the most recorded interaction, both for elasmobranchs and teleosts. This may be due to greater observation efforts and the development of methods to verify plastic intake, due to potentially harmful plastic effects on human health, due to trophic transference. However, about 25% of the interactions reported for elasmobranchs refer to entanglement, an uneven proportion compared to entanglement records for teleosts (1%).

Another possibility is that entanglement results in faster lethality, being more difficult to register. Notwithstanding, no conclusions can be made regarding higher elasmobranch vulnerability to entanglement, as differences in efforts concerning teleosts thwart the possibility of any comparison. Abbasi et al. (2018) recorded another type of teleost interaction, namely the presence of plastics in gills. This type of interaction has not yet been assessed, with still unknown deleterious effects, the most intuitive of which being suffocation.

The most reported materials were microplastics (e.g. Ramos et al. 2012; Collard et al. 2015, 2017; Ferreira et al. 2016; Pazos et al. 2017; Pegado et al. 2018; Sampaio et al. 2018), although we do not believe that these materials are preferentially ingested. The highest incidence of this type of plastic is probably due to the greater effort in detecting these materials. Larger plastics, such as meso- or macroplastics, besides exhibiting less biota interactions, may be more harmful and cause quicker animal death, which may complicate sampling, leading to non-reporting of these interactions. However, any conclusion in this sense is fragile, as not enough information is available to define these interactions.

Color reporting is important to attempt intake pattern trends, as it is possible that specific colors may lead to increased or decreased interactions, as certain plastic colors may be consumed at higher frequencies due to similarity with certain prey items. Composition is also important, for the same reason, with the added fact that these residues, due to certain characteristics, such as density, may influence distribution sites. Material shape is also an important variable to be reported, and a considerable diversity was noted in the assessed studies. Yet, clear preferences were not observed and cannot support any speculation regarding behavioral patterns.

The results demonstrate a lack of method standardization and reported items, as observed by other studies (e.g. Jabeen et al. 2017; Lusher et al. 2017a, b; Collard et al. 2019). This is inevitable in a new and still immature field of research, in which several fronts work in parallel to develop strategies to better understand the subject. The main problem with a lack of method standardization is that it is difficult to compare data from studies that apply different methodologies, as each method has its own limitation and thus, a report of zero occurrence of plastic ingestion for a given species may be due to the fact that the applied method was not the most appropriate. Markic et al. (2020) verified a significant increase in intake reports when using gastrointestinal digestion techniques, alongside stereoscopic microscope assessments, corroborating Jabeen et al. (2017), although for macrocarnivorous fish such as large sharks, stomach content chemical digestion may not be viable and, thus, the use of more limited methods is understandable.

Several studies mention plastic waste interactions with marine biota. However, they often do not report the type of material, such as size name, do not follow material’s shape name standardization and often do not register plastic colors, and when they do, they usually do not quote which directives the authors are following, as also noted by Collard et al. (2019)

when reviewing studies conducted in freshwater fishes. Several standardization proposals for plastic waste size records are available (Hanke et al. 2013; GESAMP 2015, 2019; Lusher et al. 2017a; Hartmann et al. 2019). However, there is no consensus in the scientific community as to which is best, limiting data comparisons. Furthermore, a considerable part of the studies does not report material composition, as no polymeric analysis of microplastic particles was carried out. Some studies that mention larger particles, such as macro- and meso- plastics, as well as microplastics, did not clarify shape associated to size. A clear report on macro- and micro- sizes is essential to understand occurrence patterns and paramount in conservation, management and policy actions. A total of 47 colors and 45 shapes were reported, indicating the need to standardize these variables. Herein, we propose some standardized shapes and colors, a combination of the most cited in the evaluated papers, excluding less reported synonyms, as an incentive to future authors to follow this standardization. The proposed colors are black, blue, brown, green, grey, red, colorless, white, yellow, orange, pink, purple and multi-colored. It is also important to report if the particle is transparent, translucent or opaque as, even though these characteristics are not colors, as some authors reported, they are overall important aspects to report. The proposed shapes comprise the following: fragments: irregular shaped hard pieces; films: flat, sheet-like, very soft and easily malleable; fibers: multifilaments either bonded, twisted, braided and/or woven threads; filaments: monofilaments lines, single threads, not braided, woven, bonded or twisted; spheres: spherical objects such as beads and balls; pellets: cylindrical, rounded or ellipsoidal; foams: compressible and smooth.

Davidson and Dudas (2016) demonstrated that visual analyses identifying plastic composition are misleading for about 70% of the particles. Due to easy access and an adequate cost benefit relationship, most polymeric identification in the evaluated studies was carried out by FT-IR, corroborating the reviews carried out by Kroon et al. (2018), Collard et al. (2019) and Markic et al. (2020). This is important, as polymeric analyses serve as confirmation that the suspected and selected particle after visual inspection is in fact a plastic polymer, a natural or a semi-synthetic particle (Remy et al. 2015; Lusher et al. 2017b). In our survey, we observed that some authors did not distinguish between synthetic and semi-synthetic particles as proposed by Kroon et al. (2018). This may result in neglecting the specific occurrence of semi-synthetic particles and an erroneous report of “microplastic”, for example, leading to misuses of this term.

Concerning entanglement, no clear sampling methodology or developing technologies for recording this in fish are available. Only one study reported entanglement while developing a fish sampling method, applying visual census, in coral ecosystems in Brazil (Nunes et al. 2018). This indicates that efforts should also be carried out to standardize and develop methods for other possible types of interaction. Parton et al. (2019) found that there are more entanglement reports available on Twitter than in scientific publications, suggesting that scientist capacity is limited, while other sectors directly linked to the sea, such as tourism and fishing, can better observe these interactions. Coll et al. (2014) claim that, due to the fact that fishers are direct observers of the sea, they can provide information that has not yet been recorded by scientists, inspectors or managers. Thus, citizen science can more easily provide information about marine organism interactions with solid waste, especially in entanglement cases. The idea that citizen science can actually help report the impacts of solid waste on biota has also been considered by other studies (e.g. Colmenero et al. 2017; GESAMP 2019; Parton et al. 2019). Consequently, scientists can ally themselves with the fishing and tourism sectors to provide record observations and subsequently allocate the data in publications, similar to what was carried out by Coll et al. (2014), Colmenero et al. (2017) and Bergmann et al. (2017). Another option is the creation of online platforms where people can send their information, as used by Seitz and Poulakis (2006). Thus, it is necessary for the scientific community to concentrate efforts to fill knowledge gaps and consolidate methodological bases for verifying interactions between plastic waste and marine fish, assisting decision-making in conservation policies.

3.6 Conclusions

Greater efforts regarding plastic waste interaction with marine fish are required concerning Holocephali, Agnatha and Sarcopterygii, to quantify potential threats, alongside growing concerns regarding ocean pollution and the establishment of new methodologies and technologies, which have led to an increasing number of studies on the subject. However, the spatial distribution of articles reports only the most studied areas, not necessarily the most polluted ones. Even though a considerable number of fish species has been analyzed to date, only a small fraction of all species has been evaluated. This lack of information is aggravated for elasmobranchs, which are neglected due to higher efforts used to assess teleosts. Ingestion is the most reported interaction. Entanglement and other interactions, on the other hand, require the application of other methodologies so that may be adequately quantified. Nonetheless, concerning ingestion studies, residue description (size, color, shape and composition, among others.) is flawed, compromising the identification of possible patterns. Due to this lack of data, citizen science, which is underutilized, can be a valid tool to generate this type information and rapidly expand knowledge on this subject.

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4. CONCLUSÃO

A interação dos peixes marinhos com os resíduos sólidos necessita de um intenso e elevado esforço na avaliação para quantificar suas ameaças, em especial para Holocephali, Agnatha e Sarcopterygii. Mesmo os teleósteos que são o grupo mais estudado e reportado, mas devido ao seu número de espécies ser consideravelmente maior que os demais taxa, ainda é um número extremamente pequeno, comparado a riqueza específica do ecossistema marinho. Isso apesar do estabelecimento de novas metodologias e tecnologias para monitoramento e avaliação da poluição plástica nos oceanos, junto com um aumento na preocupação sobre o tema, fornecer um aumento no número de estudos referente ao assunto. Entretanto a distribuição espacial dos artigos não reporta interações nas regiões por essas serem mais poluídas *per se*, reporta, todavia, as regiões mais estudadas, onde houve um maior esforço de amostragem. Quando comparado o esforço de amostragem dos teleósteos frente aos elasmobrânquios, estes são negligenciados.

A interação mais reportada é a ingestão, muito provavelmente pelo maior interesse em detectar esta interação por preocupações com a segurança alimentar humana. O que gerou maiores esforços para o desenvolvimento de metodologias que buscam observar este tipo de interação. Em contrapartida, o emaranhamento e outras possíveis interações necessitam do desenvolvimento de metodologias para que efetivamente possam ser avaliadas. Todavia ainda assim há falhas nos estudos que reportam ingestão, frequentemente não reportando apropriadamente a descrição dos resíduos encontrados como cor, tamanho e etc, dificultando a identificação de possíveis padrões de distribuição e ocorrência. Frente a ausência de dados, e a dificuldade em se obter informações a ciência cidadã, frequentemente subutilizada e por vezes negligenciada, pode ser uma excelente ferramenta para produzir dados e ampliar o esforço de observação do conhecimento ante esta área. Através de relatos e coleta de material por pescadores, surfistas e banhistas que comumente tem maior tempo dedicado a interação com o meio marinho do que os membros da academia.

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